The Collaboratory for Support of Scientific Research

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This paper was prepared for submittal to
Workshop on Remote Participation in Fusion Experiments
(Satellite Meeting to the 1998 EPS Conference)
June 28-29, 1998
Prague, Czech Republic

June 25, 1998

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The Collaboratory for Support of Scientific Research

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Introduction

Collaboration is an increasingly important aspect of magnetic fusion energy research. With the increased size and cost of experiments needed to approach reactor conditions, the number being constructed has become limited. In order to satisfy the desire for many groups to conduct research on these facilities, we have come to rely more heavily on collaborations. Fortunately, at the same time, development of high performance computers and fast and reliable wide area networks has provided technological solutions necessary to support the increasingly distributed work force without the need for relocation of entire research staffs. Development of collaboratories, collaborative or virtual laboratories, is intended to provide the capability needed to interact from afar with colleagues at multiple sites. These technologies are useful to groups interacting remotely during experimental operations as well as to those involved in the development of analysis codes and large scale simulations.

The term “collaboratory” refers to a center without walls in which researchers can perform their studies without regard to geographical location – interacting with colleagues, accessing instrumentation, sharing data and computational resources, and accessing information from digital libraries [1],[2]. While it is widely recognized that remote collaboration is not a universal replacement for personal contact, it does afford a means for extending that contact in a manner that minimizes the need for relocation and for travel while more efficiently utilizing resources and staff that are geographically distant from the central facility location, be it an experiment or design center. While the idea of providing a remote environment that is “as good as being there” is admirable, it is also important to recognize and capitalize on any differences unique to being remote [3].

Magnetic fusion energy research is not unique in its increased dependence on and need to improve methods for collaborative research. Many research disciplines find themselves in a similar position, trying to better utilize facilities and increase productivity for both local and remote researchers. A recently published issue of Interactions [4] includes a special section dedicated to collaboratories. A description of collaborative observations at the Keck Observatory [2] indicates distinct and real advantages gained by astronomers who can now remotely access this facility, even as the collaboratory is developing. Advantages range from simply making the facility available to more researchers without the cost of travel to the physiological advantage of not experiencing oxygen deprivation sickness due to high altitude observing. The Upper Atmospheric Research Collaboratory [2] which focuses on studies of the earth’s ionosphere and interactions with the solar wind now combines information from several observing sites, many in difficult to reach high latitude locations above the arctic circle. Travel to these remote locations, formerly provided by military flights which are no longer needed, is now more expensive for researchers. With a now obvious need for remote sensing and collaborations, the UARC has combined access to these experimental facilities and joined in global modeling efforts to better use the capabilities of researchers on an international scale. The final collaboratory featured [2] is that of our testbed development for the DIII-D tokamak experiment [4] to make it even more accessible in its role as a US national facility.
Background, Fusion Collaboratory Testbed

We originally proposed the idea of a Remote Experimental Site (RES) [5],[6] as an operations center, geographically distant from the experiment, that provides the functionality necessary to conduct physics experiments. This concept was a direct outgrowth of networking development for local control and data acquisition systems for fusion experiments at the Lawrence Livermore National Laboratory (LLNL) and other sites. The RES [7] development was initially internally funded at LLNL to develop the wide-area-network (WAN) versions of local control and data acquisition concepts and forms the basis for the collaborative development deployed at DIII-D.

A collaborative project, the Remote Experimental Environment (REE) was formed and funded [8] in response to the need to explore interactive access to tokamak environments, particularly in light of the ITER project which requires such access on an international scale. The development was a collaborative itself and included computer scientists from the LLNL, General Atomics, Oak Ridge National Laboratory and the Princeton Plasma Physics Laboratory who, during development, used the technologies being applied to the collaboratory. The interactive nature of magnetic fusion experiments led us to explore techniques for supporting enhanced participation in real-time operations from geographically distributed locations. REE development relied on three major capabilities.

1. Distributed utilization of data, resources and people
2. Robust, interactive communications and information exchange
3. Control of instrumentation and experimental systems from remote sites

all of which were addressed to some level in the project. Our objective was to provide a testbed [4] for exploring remote collaboration research, essentially building an initial "collaboratory" for national fusion research. The testbed is now being used to evaluate the ability of remotely located groups of scientists to conduct research on the DIII-D Tokamak. The REE serves as a test environment for advanced computing, control and collaboration concepts applicable to future experiments, like ITER, while enhancing the ability to conduct research on the existing facility.

Distributed computing environment

This testbed provides researchers with access to computing services independent of their physical location, as shown schematically in Fig 1. It uses the Open Software Foundation (OSF) Distributed Computing Environment (DCE) to develop and test concepts in distributed analysis, visualization and control. DCE security and naming services are used with global, distributed file access from the Distributed File System (DFS). Interprocess communications software [9] (IPCS) developed at LLNL provides asynchronous communication among processes in an heterogeneous computing environment [10] distributed among participating sites. IPCS provides an interface to the hardware experimental timing system and forms the basis for wide area network synchronization to the real-time experimental operations. It provides for coordination of tasks running both inside and outside of the DCE cell. An event management service [11], originally developed for local area network applications in a VMS cluster at PPPL, was modified to utilize IPCS messages for communication over the wide area network and coordination of information flow in the distributed environment. It minimizes the latency time between data availability and the initiation of processing required both for operations in the DIII-D control room and for remotely participating researchers. Similarly,
data availability and processing events are used to initiate visualization applications which generate displays and make data available for web browser applications. A library of data calls [12] allows remote access to various data elements within the experiment's file system. This process was facilitated when GA distributed the DIII-D data file system. Using event identification and distributed acquisition of data, we can better schedule information flow and processing during experiments. We are now evaluating the concepts in terms of performance and suitability of DCE/DFS to support experimental operations.

Our first full DCE application distributed the operations critical processing required to analyze the magnetic equilibrium produced during experiments. The EFIT code [13], which gives a reconstruction of the magnetic equilibrium, was modified to run in the DCE environment. Using data from many measurements now served over the wide-area network, this DCE version of EFIT allows us to greatly increase the number of reconstructed equilibria available to researchers in the control room by running parallel processing within our DCE cell. In addition to the automated processing, a web browser interface to the DCE/EFIT application, Fig. 2, provides user-friendly access to distributed computations. With the cell as currently configured, we have already realized considerable gain in processing throughput for support of experimental operations. We typically produce over 200 such reconstructed equilibria in under 5 minutes from the shot. This provides for interpretation of the time-dependent evolution of a
plasma discharge and meets the demand for intershot processing for both scientific analysis and control of the experiment.

Figure 2 Web browser interface to the DCE/EFT processing. Forms provide user-selected processing (left), control of parameters (right) and selection of computers (center).

**Operations Monitoring**

As with most tokamaks, to successfully participate in DIII-D operations, whether local or remote, a tremendous amount of information is required. The complications of being remote make this more difficult to achieve. The DIII-D data system, however, allows for routine and efficient access to most data from off-site locations. Data from only a few systems, typically those that use autonomous computers for control and data acquisition, have not been routinely available. This situation is currently changing as DIII-D converts to use of MDSplus data system [14].

For personal communications, we rely on both text-based and audio/video communications. Internet Relay Chat (IRC) [15] has historically provided a location-independent means of communication from the desktop. IRC software is free and interoperates under UNIX, Macintosh and PC environments. We have developed a Java-based...
graphical interface to create a multi-channel communications tool that is routinely used, Fig. 3. Via this tool, participants at several locations can simultaneously “discuss” operations over

**Figure 3** Java chat communication tool. countdown clock (top), diaglog box (bottom), participant (right) and active session log (main box)

selectable channels reserved for specific topics such as operations or diagnostics IPCS messages provide experimental status to the Java-chat system which automatically update the date, shot number and count-down time to the next shot Shot commentaries written during operations are sent to the Java-chat system as are shot timing events used to time-stamp the operations The entire discussion is archived daily and provides a web-searchable log of the daily operations

For efficient and active participation in operations, we find it necessary to be able to see and hear what is going on in the control room We have provided a remotely controlled camera connected via the multicast backbone (MBONE) tool [16] to provide audio and video
monitoring of the operations. A web-based controller provides remote users with an interface to operate the camera to “look around the room” as one would if present in the control room. A person with sufficient control room experience can generally determine the quality of operations by merely observing activity in the control room. Announcements from the chief operator (technical staff responsible for running engineering systems) can be heard off site and most session leaders (those responsible for executing a physics run) now use the microphone to announce to the room and off site the shot setup and results of previous shots. While we have capability for 2-way discussions, most session leaders have not become accustomed to its use. We are making the necessary modifications to simplify it’s use with the hope that simplicity will stimulate use.

Remote control

Much of the instrument control now uses Xwindows-based interfaces which makes remote operation possible with a minimum of modification. Several such instruments are routinely operated with internet access by exporting the X-based control screens. Data is analyzed at remote sites with results returned to the control room during operations. Remote procedure calls and IPCS provide alternate mechanisms for connecting remote user interfaces to local (to the experiment) data acquisition, control and processing daemons without the need to export Xwindows interfaces over the network. One such instrument is the SPRED spectrometer on DIII-D. This instrument was developed specifically for network access and uses IPCS messages for control with a Tcl/Tk for the user interface, Fig 4, along with a graphics package to display the data. Access to control the vacuum system hardware, high voltage bias supplies and data acquisition is allowed except for the main tokamak vacuum valve. Remote monitoring of acquisition status for this instrument and others has been implemented with a web browser application (formerly done with X displays). Shown in Fig 5 is an active web display which is automatically updated by IPCS messages when the DIII-D control system has a transition in state, e.g., set up for a new shot or start of the data acquisition sequence. The status of various instrumentation components is available along with the shot number, date and time to the next
Similarly, plasma control, heating, and fueling systems on both Alcator C-mod and DIII-D allow for remote operation. Due to the nature of these systems, e.g., control of millions of watts of power where machine and personnel safety are issues, administrative policy generally limits the use of remote control. Security features with authentication and resource authorization are needed to make these systems more open for future remote use.

Figure 5. Live web browser display used to monitor processes over the network.

Remote Experimental Operations

The feasibility for remote operation of a fusion experiment was first demonstrated on Alcator C-mod [17]. Researchers from the Plasma Fusion Science Center at the Massachusetts Institute of Technology joined those at LLNL to operate the Alcator C-mod experiment in Cambridge, MA from Livermore, CA. At that time, only a T1 (1.6Mb/s) network connection was available which limited the audio/video communications and the data transfer rates. Researchers now regularly participate in DIII-D experiments from off site, running instrumentation and providing data processing and analysis. Recently, similar operation of the DIII-D tokamak was conducted from the LLNL site [2]. To demonstrate that an even greater level of participation is possible from remote locations, a team of scientists conducted a set of experiments on the DIII-D tokamak from LLNL using the REE to execute an approved research proposal. This included remote operations of the plasma shape control system, the 20MW neutral beam heating system, several instruments and the intershot analysis. The T3 (45Mb/s) connection was very robust and supported several audio/video channels, control and data acquisition interfaces and data analysis with the local area ethernets (10Mb/s) now becoming the limit. Our primary focus was to complete an approved set of experiments. Our goals were
to obtain information on the strengths and weaknesses of collaboration tools, to gain more insight into the number and types of communications channels needed and to provide information for development of techniques for future experiments such as ITER.

The team comprised a session leader responsible for conducting experiments, a physics operator controlling plasma shape, a physicist controlling operation of neutral beams and an analysis coordinator responsible for dissemination of experimental progress. This core group would normally fly to San Diego to be in the local DIII-D control room during operations where fine tuning of the experiment based on results obtained is generally required. We conducted the experiment jointly with participating physics personnel in the DIII-D control room and with on-site technical staff responsible for machine and personnel operations and safety.

Providing sufficient communication between the local and remote teams was the most difficult challenge. The single A/V channel typically used during remote participation in operations clearly was not enough to support the highly interactive demands of full operation. We reviewed how team members interact in the control room and determined that the minimum of A/V sessions required to demonstrate truly viable remote operations was four. We configured additional workstations to enhance our communications capabilities as shown in Fig. 6. Anyone in the control room could walk up to the remote session leader and discuss.
experiments in progress. This channel also provided multi-party communication with other off-site participants at ORNL and PPPL. Using these four channels, the only additions to the REE, we were able to keep all groups informed and safely directed operations. The team assembled at LLNL participated in the first day of operations as normally done from off site. On the second day, the remote team brought up the experiment for the second day of a Helium Plasma campaign [18]. The experiment was up and running with only routine difficulties and minimal delay due to our "remoteness". With our somewhat narrow view of the DIII-D control room, Fig. 7, we maintained operation for the entire day, took 26 shots, comparable with the first run day, and completed a defined set of experiments. Most of us felt that remoteness of the run team had little effect on the rate at which the experiment progressed. All things considered, most participants felt that this first remote operations run on DIII-D was quite successful and are quite willing to participate in such operations in the future.

Observations on Scientists at Work

An integral part of the collaboratory development is a review of how scientists function in a distributed work group [3]. Understanding the work practice of experimental scientists provides input to the design of collaboration technologies and is critical to the long-term success of these projects. Numerous scientists were interviewed before, during and after the remote operation from LLNL. For collaborators that are already remote, the desire for remote collaboration is high. For scientists on site at GA, remote collaboration is often seen as an intrusion. Education of the local staff is important for gaining acceptance. Perhaps the best
sign of success is the way in which technology supports and enhances the research activity. Indeed, acceptance of the idea is often only achieved when obvious benefits to the local research group are realized. The number of participants, the size and customization of equipment and the rapid iteration of experimental parameters challenge traditional approaches that generally are aimed at one-on-one or smaller, more isolated work groups. The fact that fusion collaborators are already geographically distributed at different laboratories provides an impetus for acceptance of new ideas. Overall the remote experiment was a success. It demonstrated the feasibility of running a full physics experiment on the DIII-D tokamak from a remote site. Productive, interactive remote participation was clearly demonstrated. Some things did not work as well as planned, but are fixable. Ideas for improvement came from many of the participants. Comments ranged from fear that the local team would be relegated to the off-hours maintenance and repair of the tokamak and thus miss the physics to excitement at the future possibilities of being in your home institution but still controlling the experiment.

Conclusions

The technology available today readily supports a high level of collaborative research as demonstrated by the robust and high performance connection to the DIII-D experiment. It supports fast and routine data sharing, analysis and remote access to instrumentation. Additional A/V channels would be very useful. Ideally every workstation and terminal in the control room should be so equipped and, indeed, it is required for true integration of remote and local participants. Network bandwidth is certainly an issue, in the US, this is rapidly disappearing as an impediment. Many laboratory sites are already connected at speeds higher than T3 and network infrastructure is being improved to many University sites under government funding for Internet II. While robustness and ease of operation are still issues, the most serious technological issues requiring development at this time is the deployment of security architectures and authentication schemes. Authentication using levels of permission is needed to insure that even valid collaborators do not wander off into systems where they have not been properly trained. At this point, perhaps the major impediment to remote science is one of acceptance, both by the working scientists and administrators. The somewhat archaic mode of operation which focuses almost solely on local presence needs to be broadened to the virtual presence provided by collaboration technologies. Where we have seen too little progress is in the daily communications among collaborators, e.g., routine broadcast of work group meetings and the ability to virtually meet to discuss research topics. While technology can support this level of interaction, it still requires fairly knowledgeable users to make it work. The technological tools are rapidly improving and will soon leave us only to modify or work habits and environments.

Acknowledgments

Work performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under contract number W-7405-Eng-48. Funding also provided by the Distributed Collaboratory Experimental Environments Initiative, Lawrence Berkeley National Laboratory. This work has been a collaborative effort among the four geographically separated laboratories, Lawrence Livermore National Laboratory, General Atomics, Oak Ridge National Laboratory and Princeton Plasma Physics Laboratory and many
individuals within those laboratories especially S. Davis at PPPL, B. McHarg at GA and D. Greenwood at ORNL. Special thanks is extended to the DIII-D operations group for their patience, understanding and willingness to attempt the remote operations and to those who actively participated in the experimental run. We also wish to acknowledge the useful interactions with S. Bly of Sary Bly Consulting for her very insightful evaluation of the way we work in our experimental environment.

References


